114
A1-PS2

Session 2022

Alleviation of Subsynchronous Torque Oscillations in Series Compensated Power Grid Via Fuzzy Based Battery Energy Storage System

Mohamed FAYEZ
Cairo Electricity Production Company (CEPC)
Egypt
eng_mf69@yahoo.com

SUMMARY

The application of series capacitor banks in lengthy transmission corridors, generally more than 240 Km, has been long recognized as posing a potential hazard to steam prime movers driving synchronous machines after the unfortunate Mohave shaft failure incidents back in the seventies. Series compensation has been broadly utilized since the early fifties for transferring large blocks of electric power over lengthy transfer distances in a cost-effective approach. The utilities have gained so many overwhelming merits from series capacitor banks which making them extremely indispensable for long transmission corridors. Series compensation allows for heavier power transactions through the existing transmission facilities without the urge for constructing additional transmission projects. It also enhances the voltage profiles of the connected busses, and thereby the threshold of voltage instability is consolidated. Moreover, network angular stability is boosted via series capacitor banks. Unfortunately, power grids incorporated with series capacitance elements are highly vulnerable to be exposed to subsynchronous resonance (SSR) conditions where the rotor system of steam turbogenerators and the network are exchanging energy at one of the torsional resonance modes of oscillations. From the mechanical perspective, SSR conditions causes intense torque oscillations with periodically escalating amplitudes at the distinct shaft sections and as a consequence an 100% fatigue life wastage of the shaft material is surely expected. Thus, the shaft is destined to suffer from low-cycle fatigue surface cracking which is a precursor to a complete fracture of the shaft. SSR conditions developed in Navajo and Mohave thermal generating stations have fed off the utility's enthusiasm about this highly destructive phenomenon to find out SSR countermeasures and emphasized the pressing need to implement them as soon as possible. Battery energy storage system (BESS) is going to have a wide-spread appearance in modern power systems since the unceasing transition of many countries to possess increasingly higher penetration levels of sustainable energy resources in their electricity portfolios. Fuzzy-based BESS is proposed in this work for neutralizing SSR conditions. BESS is simply a battery bank interconnected to the network via a bidirectional DC-to-AC power converter and step-up coupling transformer. In this work, a local control signal synthesized from the generator rotor speed is applied to the fuzzy controller to orchestrate the real power injection strategy of the installed BESS. Demonstrating the effectivity of the propositioned scheme is accomplished by performing a non-linear time-domain simulation study on the well-known IEEE second benchmark via MATLAB/Simulink-based modelling and simulating platform. The test system is subjected to self-clearing three-phase to ground fault to demonstrate the effectivity of propositioned scheme for alleviating the severe mechanical torque oscillations. The results plot the torsional torque responses without and with the proposed alleviation scheme to demonstrate its ability to neutralize the SSR conditions. excellent levels of the torsional torque profiles have been reached reach after the proposed scheme implementation. Moreover, implementing the proposed scheme should facilitate applying of series capacitor banks in lengthy transmission corridors emanating from fossil-fuelled generating stations soundly and safely without putting the mechanical integrity of turbogenerator shaft system into imminent danger.

KEYWORDS

Battery Energy Storage System; Fuzzy Logic Control; MATLAB/Simulink; Subsynchronous Torque Oscillations.

1. INTRODUCTION

The application of series capacitor banks in lengthy transmission corridors, generally more than 240 Km, has been long recognized as posing a potential hazard to steam prime movers driving synchronous machines after the unfortunate Mohave shaft failure incidents back in the seventies [1-4]. Series compensation has been broadly utilized since the early fifties for transferring large blocks of electric power over lengthy transfer distances in a cost-effective approach [5]. The utilities have gained so many overwhelming merits from series capacitor banks which making them extremely indispensable for long transmission corridors. Series compensation allows for heavier power transactions through the existing transmission facilities without the urge for constructing additional transmission projects [6]. It also enhances the voltage profiles of the connected busses, and thereby the threshold of voltage instability is consolidated. Moreover, network angular stability is boosted via series capacitor banks [5]. Unfortunately, power grids incorporated with series capacitance elements are highly vulnerable to be exposed to subsynchronous resonance (SSR) conditions where the rotor system of steam turbogenerators and the network are exchanging energy at one of the torsional resonance modes of oscillations [1-4].

The researchers usually consider the shaft of turbogenerator, in studying the vast majority power system dynamic problems, as an individual mechanical system with a definite intertia constant [1]. In the real-life, the shaft system is not in this elementary form. It is structured from a number of massive rotor elements characterized by their considerably high intertia and their relatively large diameter [1]. These rotor elements are then rigidly linked in tandem at thinner rotor extensions [1]. The large utility-scale shaft system can reach up to 50 meters in total length with several hundred tons as a total weight [1]. The turbine-generator shaft is modelled as spring-mass arrangement for studying the torsional torque oscillations experienced at the shaft extensions [1]. SSR torsional torque oscillations is a problem of an overwhelming attention inside the power engineering community [1-4]. SSR is a transmission system-based power system dynamic problem that certainly has adversely devastating effects on the turbine-generator sets operating under this circumstance [2]. Therefore, SSR could be considered as multidisciplinary power utility problem. From the mechanical perspective, SSR conditions causes intense torque oscillations with periodically escalating amplitudes at the distinct shaft sections and as a consequence an 100% fatigue life wastage of the shaft material is surely expected. Thus, the shaft is destined to suffer from low-cycle fatigue surface cracking which is a precursor to a complete fracture of the shaft [1-4].

In the early seventies, a 909 MVA turbogenerator at Southern Nevada Mohave thermal power plant, had experienced a collector ring failure in the high-pressure unit exciter shaft due to the SSR interaction [2]. To visualize the devastating consequences of that memorable accident, Figure 1 shows the collector shaft [2].

Figure 1. Shaft damage at Mohave power plant [2]

Few years later, the turbogenerators in Navajo thermal generating station had encountered SSR conditions led to various operational difficulties. SSR conditions developed in Navajo and Mohave thermal generating stations have fed off the utility's enthusiasm about this highly destructive phenomenon to find out SSR countermeasures and emphasized the pressing need to implement them as soon as possible [6].

Batteries are the most mature and the most used method to store electrical energy [21, thesis]. Batteries are depending on two main reaction types, namely reduction and oxidation chemical reactions, or redox reactions for short [7]. The various battery types for large scale applications are commonly known by the acronym 'BESS' for battery energy storage system. Batteries are converting the electrical energy during charging into potential chemical energy and releasing the electrical energy from chemical energy during discharging [7].

BESS is going to have a wide-spread appearance in modern power systems since the unceasing transition of many countries to possess increasingly higher penetration levels of sustainable energy resources in their electricity portfolios. The development of multi-MW scale BESSs accomplishes a very significant task of amalgamating the resources of renewable energy with the dispatchable load by extenuating the intermittency nature of solar PV and wind energy resources [7].

Electric power systems have many real-life examples of multi-MW scale BESSs as a consequent result of the escalated developmental accomplishments in the scopes of power electronic converters and batteries technology [8]. Multi-MW scale BESSs are considered as one of the most significant engineering breakthroughs in electric power systems and have recently been paid much more attention by utility, industry, and academia [9]. There are many applications for BESSs in electric power systems such as regulating the grid frequency, shaving peak loads, relieving electric transmission congestion, improving the grid voltage profile, extenuating the intermittency nature of the renewable energy resources, charging electric vehicle, and enhancing the grid reliability [9, 10].

Other applications involve load following in case of heavy load variations [28], mitigation of low-frequency inter-area power oscillations, contributing in the system restoration as a quick start reserve in case of complete blackout accidents, and providing "Arbitrage" which is simply a process of time-of-day electric energy shifting [9, 10]. The nominal capacity of modern utility-scale BESSs can reach up to 300 MWhr [9].

There are many types of batteries in the grid-scale applications, such as lead–acid (Pb–acid), nickel–cadmium (Ni–Cd), sodium–sulfur (NaS), and lithium–ion (Li–ion). Flow batteries are emerging electrochemical energy storage technology [21]. There are three main types of flow batteries, such as vanadium redox batteries, zinc–bromine batteries, and polysulfide–promide batteries [11]. Pb-acid batteries have been broadly implemented in Multi-MW scale BESSs due to their relative cheapness, high response time, reasonable reliability, minor daily self-discharge, high level of maturity in the industry, and virtually complete recyclability [12-14]. The research and development activities on Pb–acid batteries have been underway for over 160 years since their invention by the French scientist Gaston Plante [13]. Pb–acid batteries have been so long implemented in the greater majority of electric power system applications [14].

The first Multi-MW scale Pb-acid based BESS project was 14 MWhr BEWAG storage facility which was commissioned in 1986 at Berlin, Germany [12, 13]. It was utilized as a spinning reserve asset and as a grid frequency regulator for western Berlin [12, 13]. In 1988, Southern California Edison (SCE) utility company has commissioned 40 MWhr Pb–acid BESS project at Chino substation, California, USA [12, 13]. It was used as a peak load shaver, electric load leveler, grid frequency controller, grid voltage controller, low-frequency power oscillations damper, and a black starter asset for the grid in case of blackout events [12, 13]. In 1994, the Electric Power Authority of Puerto Rico was commissioned 14 MWhr Pb-acid based BESS project for providing frequency and voltage support in the Puerto Rican power grid [31]. Another grid-scale Pb-acid BESS was commissioned by the South African Electric Power Authority for providing peak shaving power in the peak periods [13].

Reducing the rotor speed deviation of the neighboring turbine-generators is a key factor in any mitigation candidate for shaft torsional oscillations. BESS achieves fast injection and absorption of real power at the point of common coupling (PCC) which can help decrease the shaft speed deviation of the neighboring turbogenerators [15].

However, the rapid discharging/charging cycles, especially in the mitigation of high-frequency torsional oscillations, will have dramatic effects on the lifetime expectancy of the involved battery system [15-17]. Therefore, the injection of real power only is considered in this thesis and a dynamic resistor brake will be utilized to consume the excess real power. Nevertheless, the estimation of the lifespan of the involved battery system is not the main scope of this work.

The configuration of a typical BESS is schematically elucidated in Fig. 2. It is composed of a battery bank, DC-to-AC power converter, an inductance filter, and an isolation step-up transformer [18]. The DC power supplied by the battery bank is converted to three-phase AC power via three-level neutral point clamped inverter and interfaced to the transmission grid via an inductance filter and a step-up coupling transformer. It is very well known that three-level neutral point clamped (NPC) DC-to-AC inverter is a prevalent topology for BESS operation, so it will be utilized in this thesis [18]. Notably, the inductance filter is the most recurrently utilized in the grid-tied inverters, so it will be used in this work.

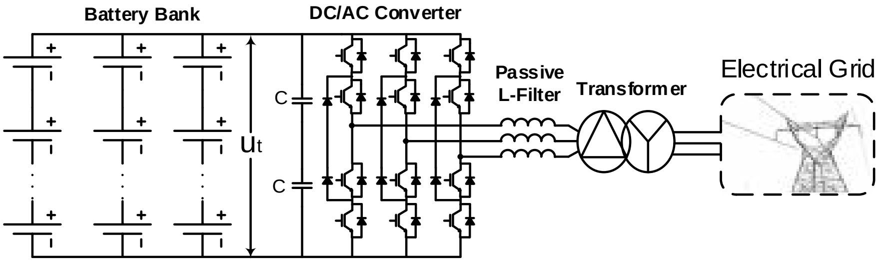


Figure 2. Regular structure of BESS linked to the grid

The modified Shepherd model is selected in this study to represent the battery bank which has been widely employed in many literatures because it is distinguished by its simpleness and maturity [19]. This battery model was introduced to the academic community by the National Renewable Energy Laboratory (NREL) in the mid-nineties of the previous century and it is distinguished by its simpleness [19].

A control signal synthesized from the generator mass speed is utilized in this work as local control input signal to the fuzzy controller to orchestrate the power injections strategy of the installed BESS. The BESS is either discharging active power or in idle operation mode based on the control signal produced by the fuzzy system. For demonstrating the effectiveness of the proposed scheme, non-linear time-domain simulation study is performed on the well-known IEEE second benchmark test system via MATLAB/Simulink-based modelling and simulation environment. Comparative simulation studies of the test system after being subjected to three-phase to ground fault condition should demonstrate the effectuality of proposed regime for mitigation of SSR torsional torque oscillations.

The remaining of this article is structured as follows. In section 2, the system under study is briefly described. Section 3 presents the concept of utilizing the fuzzy control for orchestrating the active power injections of the proposed BESS Scheme. Section 4 delineates the comparative time domain simulation results with comments. Section 5 draws the main conclusions of the article. At last, the references used to accomplish this article are enumerated.

2. SYSTEM MODEL

The well-known IEEE 2nd benchmark model is considered in this paper to test the capability and the effectivity of the BESS controlled via fuzzy system on tempering the SSR oscillations. Fig. 3 depicts the one-line diagram of the benchmark model together with the detailed mechanical turbogenerator rotary shaft system, fuzzy controller, and the BESS [20]. The benchmark model is comprised of a synchronous machine, rated at 600 MVA, 22 kV, and 3600 rpm, connected to an infinite bus via generator step-up (GSU) transformer, rated at 600 MVA, 22 kV:500 kV, and double extra-high voltage (EHV) transmission lines [20]. Transmission line (A) is equipped with series capacitance elements [20]. The electrical parameters for the synchronous generator are obtained from [20]. The electrical parameters of the EHV lines and the GSU transformer with 100 MVA as a common base power, in per unit (p.u.), are also borrowed from Ref. [20]. Like the BESS utilised in [7], 200 MWhr unit is used herein and is interconnected to the generator step-up transformer bus through 1/500 kV transformer. The parameters of the BESS are also borrowed from Ref. [7].

The machine is driven by one double-flow LP steam turbine and one HP steam turbine connected in tandem configuration [20]. The two turbine sections are equally sharing the mechanical driving torque, i.e. the sharing mechanical torque fractions are 50%, and 50%, respectively [20]. The detailed turbogenerator rotary shaft mechanical parameters are borrowed from Ref. [20]. The BESS will be momentarily energized or deenergized to mitigate the SSR oscillations by injecting active power in rotor deceleration periods. The mitigation scheme depends on the localized control signal represented by the speed deviation of synchronous machine mass to help the propositioned controller to decide the switching state of the BESS, i.e. whether the BESS is in service or not. Basically, the torsional damping related to the torsional oscillations is distinguished by its very low values especially under low-load profiles [1]. Therefore, no-load conditions are considered for the simulation studies to presume the worst-case scenarios.

For the intention of verification of the propositioned scheme effectivity, simulation studies in the time-domain via the Simulink modeling and simulation platform are performed. Examining the performance of the propositioned scheme is accomplished by considering the worst case condition characterized by the most severe fault condition.

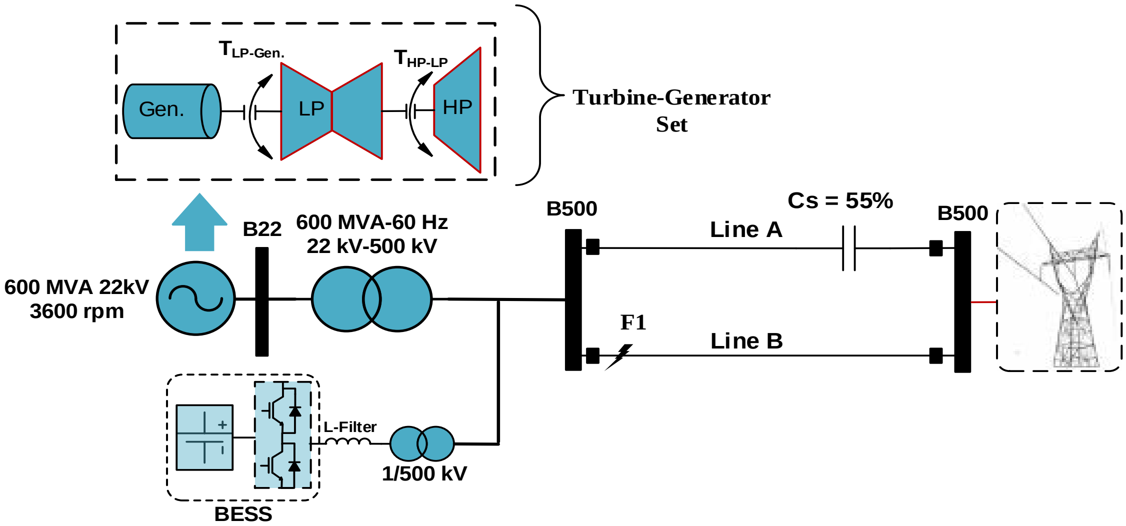


Figure 3. IEEE 2nd benchmark model with turbogenerator shaft multi-mass model incorporating BESS

The electrical parameters for the synchronous generator are obtained from [20]. The configuration of steam turbine under-study is suitably illustrated in [20]. It consists of HP section, and LP section. The turbine contributing torque fractions for the turbine sections HP, and LP are 50%, and 50%, respectively [20]. The detailed turbine-generator shaft mechanical parameters are found in [20]. The parameters of the transmission system and the generator step-up (GSU) transformer in per-unit, with 100 MVA as a common base power, are also found in [20].

3. FUZZY LOGIC CONTROLLER

The theory of fuzzy set (FS) was first presented to the academic society by the sole contribution of Zadeh in mid-sixties [21]. FS is simply an approach to interpret crisp values into varying degrees of belonging (or varying degrees of truth) using lingual variables [21]. In the traditional, i.e. nonfuzzy, set, any separate element of the universe of discourse is either belonging to the set or is not belonging to the set. Thus, the membership degree of any separate element is crisp value, i.e. it is either yes (in the set and takes the number 1) or no (not in the set and takes the number 0). In other words, FS is generic form of the traditional set. FS is able to process the concepts and notions that the humans use in their daily life such as, “very high,” “high,” “medium,” “low,” and “very low” without the necessity to know the definite ranges associated with each concept [21]. Each FS is distinguished by a unique function that determine the degrees of belonging of crisp the values usually called the membership function [21]. It is a non-linear function that determines the degrees of belonging of crisp values associated with certain lingual variable utilizing a crisp value lying in the range from 1 to 0 [21]. Membership functions have many types, such as sigmoidal or s-shaped, triangular, Gaussian, trapezoidal, and generalized bell (GB) [21].

The Fuzzy logic controller (FLC) is a rule-based controller of nonlinear type that relies on the exploitation of the expert knowledge [22]. FLCs introduce superior performance levels by exploitation the expert’s knowledge conception in treating a broad variety of multidisciplinary control issues [23].

The elementary configuration of generic FLC is typically comprised of the four primary stages: fuzzification, knowledge base, inference engine, and defuzzification which is graphically supported by Fig. 4 [22]. The fuzzification stage is responsible for mapping the crisp inputs into fuzzy variables by using normalized membership functions and irregularly input weighting factors [22]. It is simply a rule activation process [22]. In the sequent stage, the fuzzy inference engine satisfactorily determines the reasonable outputs according to the embedded fuzzy rules written by the fuzzy system designers [22]. Eventually, the defuzzification stage is responsible for converting the fuzzy control outputs into crisp values by using normalized membership functions and irregularly output weighting factors [22].

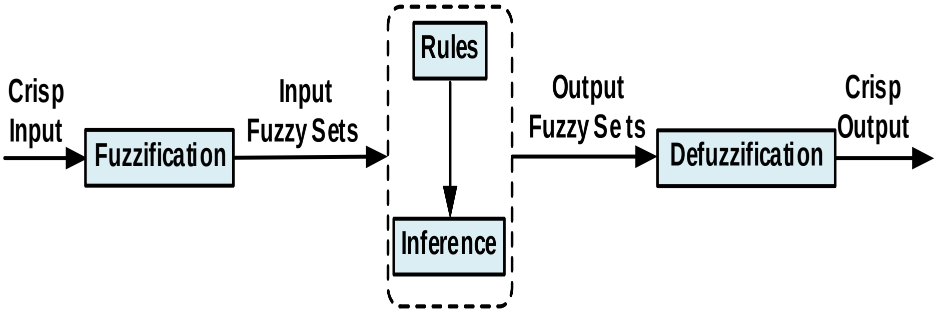


Figure 4. The general structure of fuzzy logic-based controller

Defuzzification is simply a mathematical averaging function and it is the union of all the rule consequences of the embedded fuzzy rules [22]. There are six main techniques of defuzzification, namely centroid of area, center of gravity, bisector of area or equal of area, mean of maximum, smallest of maximum, largest of maximum [22]. The defuzzification procedures, mainly in FLC with Mamdani FIS, represent heavy computational burdens in real life fuzzy applications [23]. TS fuzzy controllers do not require the defuzzification stage since the involved output membership function is either a linear function or constant value, i.e. numerically represented, which makes the TS controllers more efficient than Mamdani controllers from the computational perspective [22, 23].

Generator mass speed deviation ($\Delta\varpi$) in p.u. is selected as the input signal to the FLC while the output signal is constant with either 0 or1. The fuzzy controller takes an action when the generator rotor speed deviation signal is different from certain dead band fuzzy values. The BESS injects active power if the ($\Delta\varpi$) is negative and will be in idle mode (i.e. not discharging or charging) elsewhere. Three GB membership functions are utilized to represent the input for the proposed controller and are depicted in Figure 5.

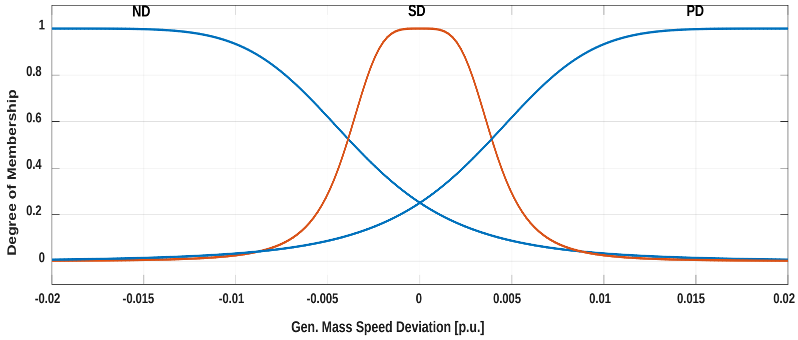
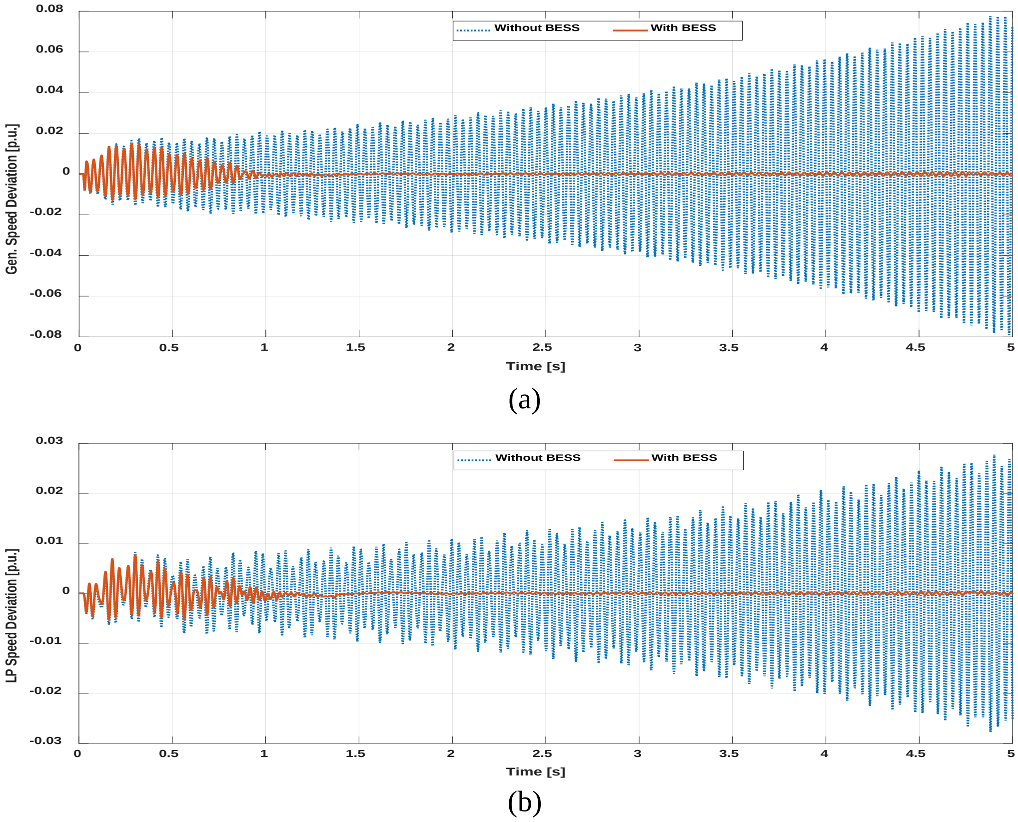


Figure 5. Membership function of generator mass speed deviation, $\Delta\omega_1$, in p.u.

Thus, the fuzzy rules should be as follows, If the input ($\Delta\varpi$) is Negative Deviation (ND) then the output is 1, If the input ($\Delta\varpi$) is Small Deviation (SD) then the output is 0, and If the input ($\Delta\varpi$) is Positive Deviation (PD) then the output is 0. The output signal of the BESS fuzzy controller will be sent to the inverter PWM control circuit to determine whether the BESS will be in discharging mood or in idle mode.

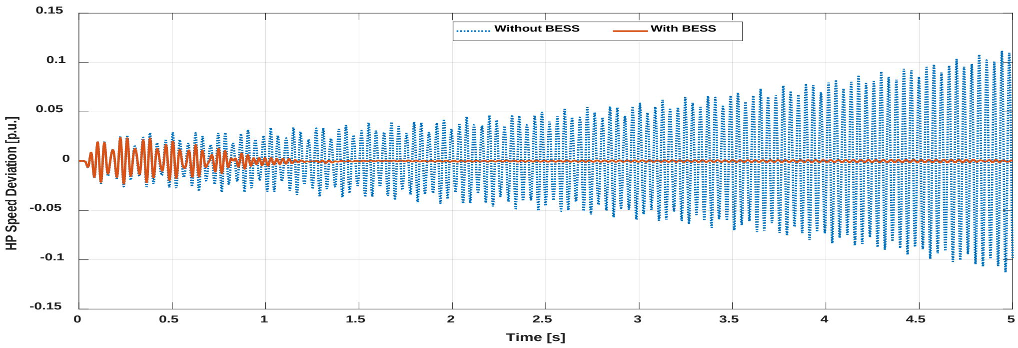
4. SIMULATION RESULTS

For verifying the effectiveness of the suggested scheme in mitigating SSR shaft torsional oscillations, time domain simulation study via MATLAB/Simulink model is conducted. Three-phase to ground (3LG) fault is applied at line B, very close to generator high voltage bus at fault point F1, as shown in Figure 3. The disturbance stimulated is a 0.0169 seconds self-clearing fault, i.e. the involved circuit breakers are not anticipated to sever the faulted line, and is applied at 0.1 second from the simulation time of 5 seconds. The relative speed responses of turbine-generator system shaft system and the torsional torque profiles in p.u. with and without the proposed scheme are listed as family of curves shown in Figure 6 and Figure 7.



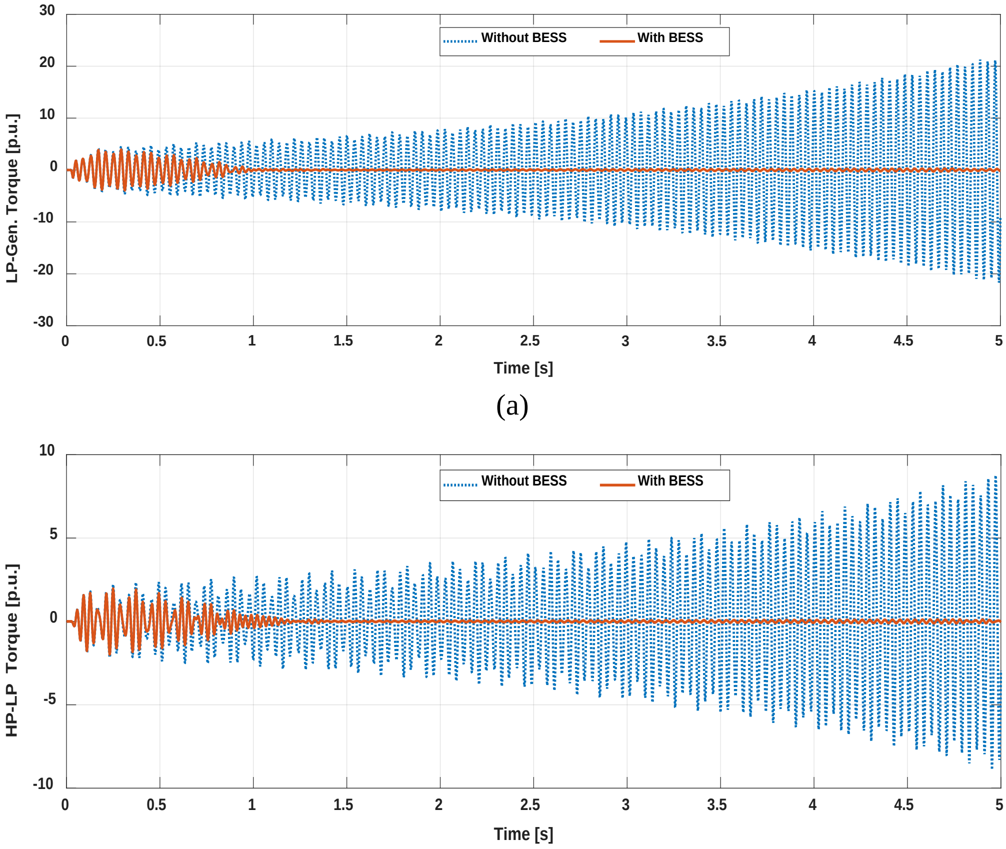
(a)

(b)



(c)

Figure 6. Relative turbine-generator mass speed responses due to the three-phase self-healing fault at the generator HV bus in p.u., (a) Generator mass speed deviation, (b) LP turbine mass speed deviation, (c) HP turbine mass speed deviation



(a)

(b)

Figure 7. Torque responses with and without fuzzy controlled BESS due to the three-phase self-healing fault at the generator HV bus in p.u., (a) LP turbine-generator shaft torsional torque, (b) HP-LP shaft torsional torque

From the above simulation, in the base case responses without the supplemental damping, it is distinctly observed that, both relative speed and torsional torque responses seem to be increasing in the time frame of the simulation which indicates the torsional instability of the responses. These devastating torque oscillations will, for sure, end up causing premature shaft fatigue life expenditure of the shaft and irrevocable shaft cracks or even a shaft fracture. As evidenced in the obtained time domain simulation results, the relative speed and the torsional torque profiles reach an excellent level due to the implementation of the proposed scheme. Neutralizing that SSR conditions further enable the employment of series capacitor compensation safely near the steam power plants without any mechanical jeopardies.

5. CONCLUSIONS

Fuzzy based BESS is a local contingency SSR mitigation scheme, where it is built inside the power plant and controlled via local control signal synthesized from the generator mass speed. This paper demonstrates the effectiveness of battery based real power injection scheme as SSR countermeasure. From the results, the speed and the torque profiles of the turbine-generator manifest a significantly excellent supplemental damping which enables the torsional responses to die out rapidly. The fuzzy based BESS could be viewed as mean for consolidating the operational security of the grid by dilating the fatigue life of the turbine-generators to the maximum possible potential by neutralizing any developed SSR situation. Finally, the implementation of proposed scheme should capacitate series capacitor compensation of long transmission lines emanating from thermal power plants soundly and safely without jeopardizing the mechanical integrity of shaft system of the involved turbine-generator set. As far as the author’s knowledge, the utilisation of battery based energy storage system, in the discharging mood only, to mitigate the SSR torque oscillations has never been discussed in the literature.

BIBLIOGRAPHY

[1] P. Kundur, “Power System Stability and Control”, (Tata McGraw-Hill, 1994, pages 1025 – 1068).

[2] EPRI Technical Report 1011679, “Steam Turbine-Generator Torsional Vibration Interaction with the Electrical Network”, (Electric Power Research Institute (EPRI), November 2005).

[3] G. Klempner, and I. Kerszenbaum, “Handbook of Large Turbo-Generator Operation and Maintenance”, (John Wiley & Sons, 2008, pages 224 – 230).

[4] P. M. Anderson, “Power System Protection”, (John Wiley & Sons, 1999, Ch.21).

[5] Mircea Eremia, Chen-Ching Liu, And Abdel-Aty Edris, “Advanced Solutions in Power Systems HVDC, FACTS and Artificial intelligence”, (John Wiley & Sons, 2016).

[6] Atia Adrees, “Risk Based Assessment of Subsynchronous Resonance in AC/DC Systems”, (Springer Theses, Springer International Publishing AG, 2016).

[7] M. F. Ahmed, M. A. Mandor, M. El-Hadidy, F. M. Bendary, “Fuzzy Based Battery Energy Storage System and Braking Resistor for Mitigation of Shaft-Torsional Oscillations,” (Journal of King Saud University – Engineering Sciences, Vol. 33, 2020, pages 589 – 600).

[8] Y. Zhu, C. Liu, K. Sun, D. Shi, and Z. Wang, “Optimization of Battery Energy Storage to Improve Power System Oscillation Damping,” (IEEE Transactions on Sustainable Energy, Vol. 10, 2019, pages 1015 – 1024).

[9] R. Hemmati, and N. Azizi, “Optimal Control Strategy on Battery Storage Systems for Decoupled Active-Reactive Power Control and Damping Oscillations,” (Journal of Energy Storage, Vol. 13, 2017, pages 24–34).

[10] D. Watsona, E. Rebelloa, N. Kiib, T. Finckera, M. Rodgersa, “Demand and Energy Avoidance by a 2 MWh Energy Storage System in a 10 MW Wind Farm,” (Journal of Energy Storage, Vol. 20, 2018, pages 371 – 379).

[11] F. D. Gonzalez, A. Sumper, and O. G. Bellmunt, “Energy Storage in Power Systems,” (John Wiley & Sons Inc, 2016).

[12] C. Menictas, M. Skyllas-Kazacos, and T. M. Lim, “Advances in Batteries for Medium and Large-Scale Energy Storage: Types and Applications,” (Elsevier science & technology, 2014).

[13] G. J. Maya, A. Davidsonb, and B. Monahovc, “Lead Batteries for Utility Energy Storage: A Review,” (Journal of Energy Storage, Vol. 15, 2018, pages 145 – 157).

[14] B. Shyam, and P. Kanakasabapathy, “Large Scale Electrical Energy Storage Systems in India-Current Status and Future Prospects,” (Journal of Energy Storage, Vol. 18, 2018, pages 112 – 120).

[15] U. Datta, A. Kalam, and J. Shi, “The Relevance of Large-Scale Battery Energy Storage (BES) Application in Providing Primary Frequency Control with Increased Wind Energy Penetration,” (Journal of Energy Storage, Vol. 21, 2019, pages 489 – 504).

[16] L. A. Wong, V. K. Ramachandaramurthy, P. Taylor, J. B. Ekanayake, S. L. Walker, S. Padmanaban, “Review on the Optimal Placement, Sizing and Control of an Energy Storage System in the Distribution Network,” (Journal of Energy Storage, Vol. 21, 2019, pages 489 – 504).

[17] J. F. Ellison, L. J. Rashkin, J. Serio, R. H. Byrne, “The Benefits of Grid-Scale Storage on Oahu,” (Journal of Energy Storage, Vol. 15, 2018, pages 336 – 344).

[18] L. S. Xavier, W. C. S. Amorim, A. F. Cupertino, V. F. Mendes, W. C. do Boaventura, and H. A. Pereira, “Power Converters for Battery Energy Storage Systems Connected to Medium Voltage Systems a Comprehensive Review,” (BMC Energy, Vol. 7, 2019, pages 1-15).
[19] A. Rufer, “Energy Storage Systems and Components,” (Taylor & Francis Ltd, 2018).
[20] IEEE Committee Report, “Second Benchmark Model for Computer Simulation of Subsynchronous Resonance,” IEEE Transactions on Power Apparatus and Systems, Vol. l04, No. 5, 1985, pages 1057-1066).
[21] R. Antão, “Type-2 Fuzzy Logic Uncertain Systems’ Modelling and Control,” (Springer, 2017).
[22] H. Altaş, Fuzzy Logic Control in Energy Systems with Design Applications,” (Institution of Engineering & Technology, 2017).
[23] Oscar Castillo and Patricia Melin, “Type-2 Fuzzy Logic: Theory and Applications,” (Springer, 2008).